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STABILITY ASSESSMENT OF C-102-23 STOPE OF THE NIOBEC MINE UNDER TECTONIC STRESSES - PART II

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Canadian Mine Technology Laboratory

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STABILITY ASSESSMENT OF C-102-23 STOPE OF THE NIOBEC MINE UNDER TECTONIC STRESSES - PART II

by

Y.S. Yu*, S. Vongpaisal*, A.S. Wong** and N.A. Toews*

ABSTRACT

A stability study of C-102-23 stope and adjacent areas, located in the upper level of Zone 1, Niobec mine, was carried out on the basis of both measured mine stress conditions, (typical of those encountered in the Canadian Shield), and gravitational loading, using the three-dimensional finite element technique.

The rock mass, for the purpose of this study, was assumed to be isotropic, and linearly elastic. The study indicated that ground conditions in terms of stability are more favourable in and around stope C-102-23 under actual stress conditions than under gravity loading.

Under actual field stress conditions, the extent of the tensile zone in the roof of C-102-23 stope is approximately 50 percent of the zone resulting from gravitational loading alone. At the centerline of the stope roof the tensile zone is approximately 5m deep and extends 5m towards both walls. In addition, small tensions can be expected to occur along almost the entire height of T-102-19 pillar. As a result, local instabilities in the stope roof and stope pillars can be expected with stope development. T-102-19 pillar is only 24m wide, and precautions should be taken to ensure its integrity.

Using values of 2 MPa and 40° for cohesive strength C and the angle of internal friction ϕ, respectively, for both the limestone and carbonatite formations, local factors of safety in terms of the Drucker/Prager yield criterion were evaluated. The values for C and ϕ that were used were considered to be conservative. Safety factors exceeding 1.3 were established for all parts of the structure. This is considered more than adequate. The implication is that conditions do not exist which will lead to shear failure in the roof or pillars of the stope. If there are failures, these will occur in tensile stress zones.

Key words: Niobec Mine, stability, stress analysis, finite element, three-dimensional

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EVALUATION DE LA STABILITÉ DU CHANTIER C-102-23 DE LA MINE NIOBEC SOUS LES CONTRAINTES TECTONIQUES - PARTIE II

par

Y.S. Yu*, S. Vongpaisal*, A.S. Wong** et N.A. Toews*

RÉSUMÉ

Une étude de la stabilité du chantier C-102-23 et des sections périphériques, dans la Zone 1 du niveau supérieur, a été entreprise sur la base des mesures des conditions de contraintes de la mine, typiques de celles rencontrées dans le bouchier Canadien, et des charges gravitationnelles en utilisant la technique de l'élément fini tridimensionnel.

Pour les besoins de l'étude, on suppose que la masse rocheuse est isotropique, et d'une élasticité linéaire. L'étude montre, qu'en termes de stabilité, les conditions de terrain sont plus favorables dans et autour du chantier C-102-23 sous les conditions de contraintes actuelles que sous une charge gravitationnelle.

Sous les conditions actuelles de terrain, l'étendue de la zone d'effort de traction dans le toit du chantier C-102-23 est d'environ 50 pourcent de la zone sous la charge gravitationnelle. A la partie centrale du toit du chantier, la zone d'effort de traction est d'environ 5 mètres de profondeur et s'étend à 5 mètres vers chaque murs. Aussi, de petites tensions peuvent être anticipées et d'apparaître sur presque toute la pleine hauteur du pilier T-102-19. Comme résultat, on peut s'attendre à des instabilités locales dans le toit et les piliers du chantier avec le développement du chantier. Le pilier T-102-19 est 24 mètres de largeur, et des précautions devraient être prises afin d'assurer son intégrité.

Les facteurs de sécurité locaux, selon le critaire d'élasticité Drucker/Prager, furent évalués en utilisant les valeurs de 2 MPa et de 40°, pour la force de cohésion C et pour l'angle de friction interne ϕ, respectivement, et pour aussi bien les formations de calcaire que de carbonatite. Les valeurs de C et de ϕ sont des estimés qui sont considérés conservateurs. Les facteurs de sécurité dépassant 1.3 ont été établi pour toutes les parties de la structure, ce qui est plus que satisfaisant. Ceci implique que les conditions menant aux ruptures de cisaillement dans le toit ou les piliers du chantier, ne sont pas présentes. S'il y a des ruptures, ceci se passsera dans les zones d'effort de traction.

Mots-clés: Mine Niobec, stabilité, analyse de traction, élément fini, tri-dimensionnel

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1.0 INTRODUCTION

A co-operative research project was initiated in 1985 between Niobec Mines Ltd., Centre de Recherches Minérales, of the Province of Quebec, and the Mining Research Laboratories(MRL) of CANMET. Numerical modelling is an integral part of this project, which has the following objectives:

(a) to contribute to the development of a geomechanical data-base on the physical and mechanical properties of the local mine rocks;

(b) to determine the field stresses at the mine, and to design and test instruments to monitor stress changes as mining progresses;

(c) to assess the regional and local stability of the mine structure by means of numerical simulation; and

(d) to provide design guidelines for mine design and ground control for use by mine personnel.

Tasks of item (a) are being carried out by Centre de Recherches Minérales, Quebec, while tasks of items (b) to (d) are being carried out by the Mining Research Laboratories, CANMET. In situ stress determinations were conducted in 1986, and established the stress conditions used in this analysis[1].

This report is part II of a series of three-dimensional finite element analyses studies. In it, the stability of C-102-23 stope in the upper level of Niobec Mine using limited field stress information was analysed.

2.0 NIOBEC MINE

Project background information and the general geological conditions and mine lay-out of the Niobec Mine have been described in a previous report [2]. For completeness, a plan view of the mine at the 300 level and a longitudinal section (157+50N) are provided in Figs. 1 and 2, respectively. C-102-23 stope at the upper level is currently under development. The planned stope span is 73m (240 ft). Because of the large span the mine is concerned about the stability of the stope and adjacent areas. This study is directed at evaluating the stability of C-102-23 stope.

2.1 3-D Niobec Mine Model

An isometric view of the finite element model used in the study is shown in Fig. 3.

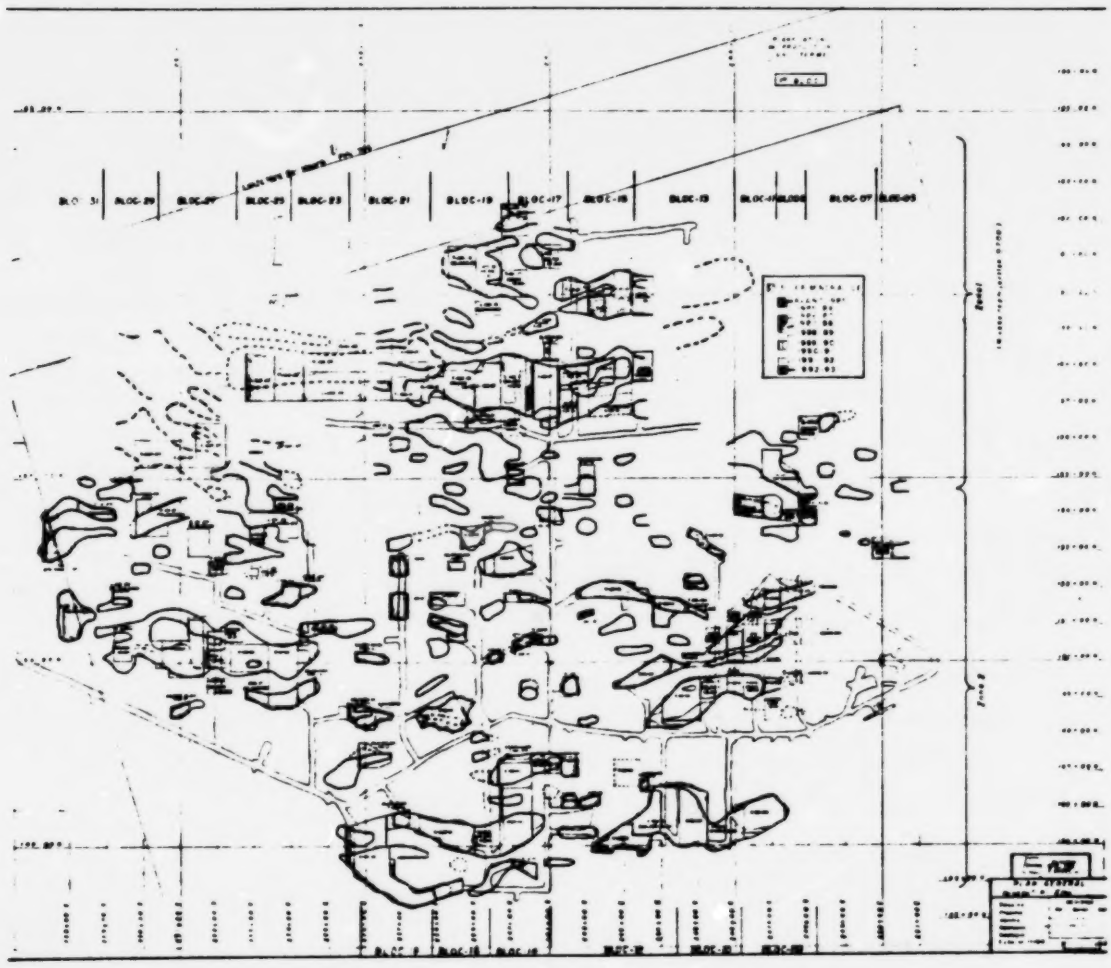


Fig. 1 Plan View of the Niobec Mine at Level 300

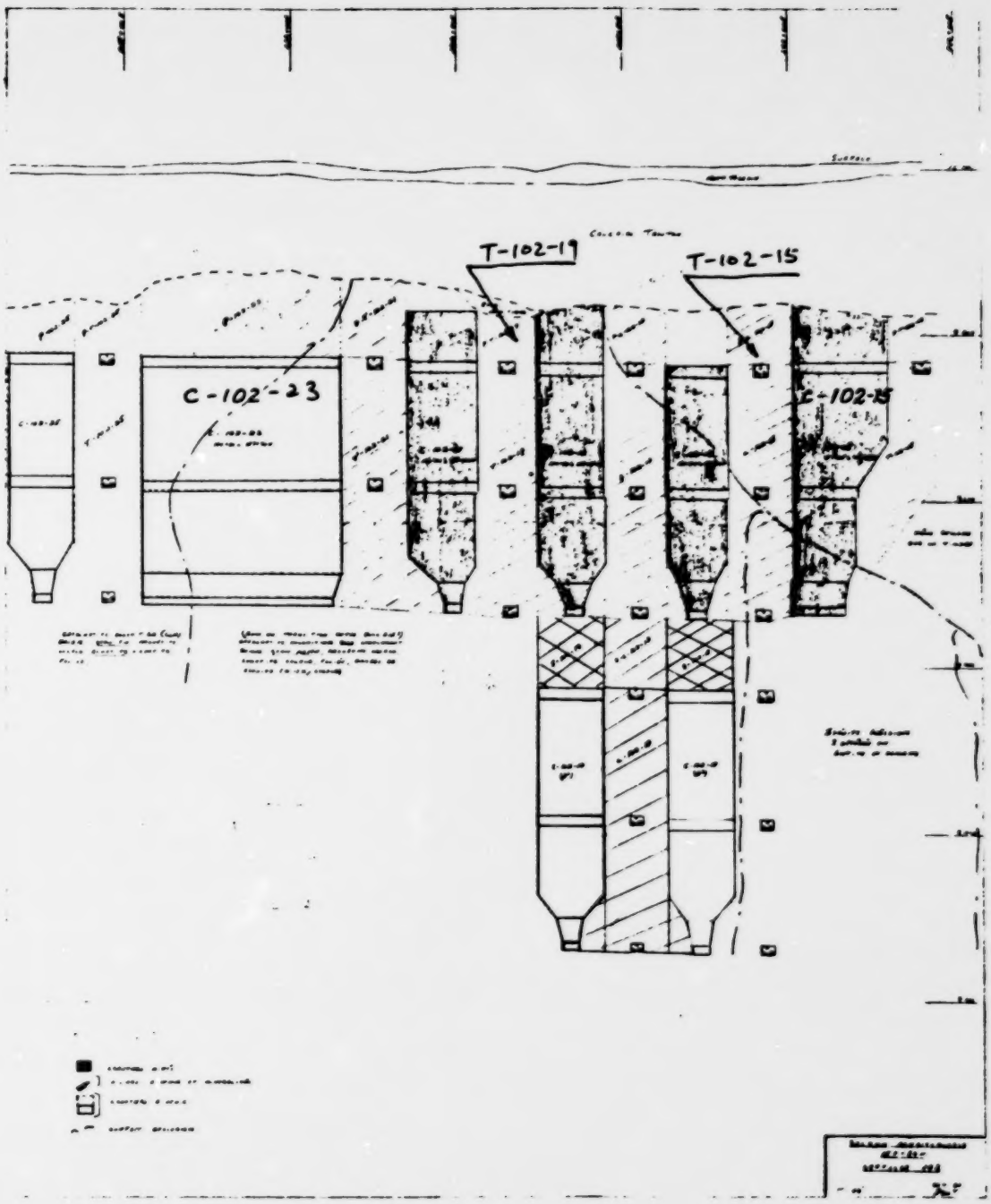


Fig. 2 Longitudinal Section 157 + 50N of Niobec Mine

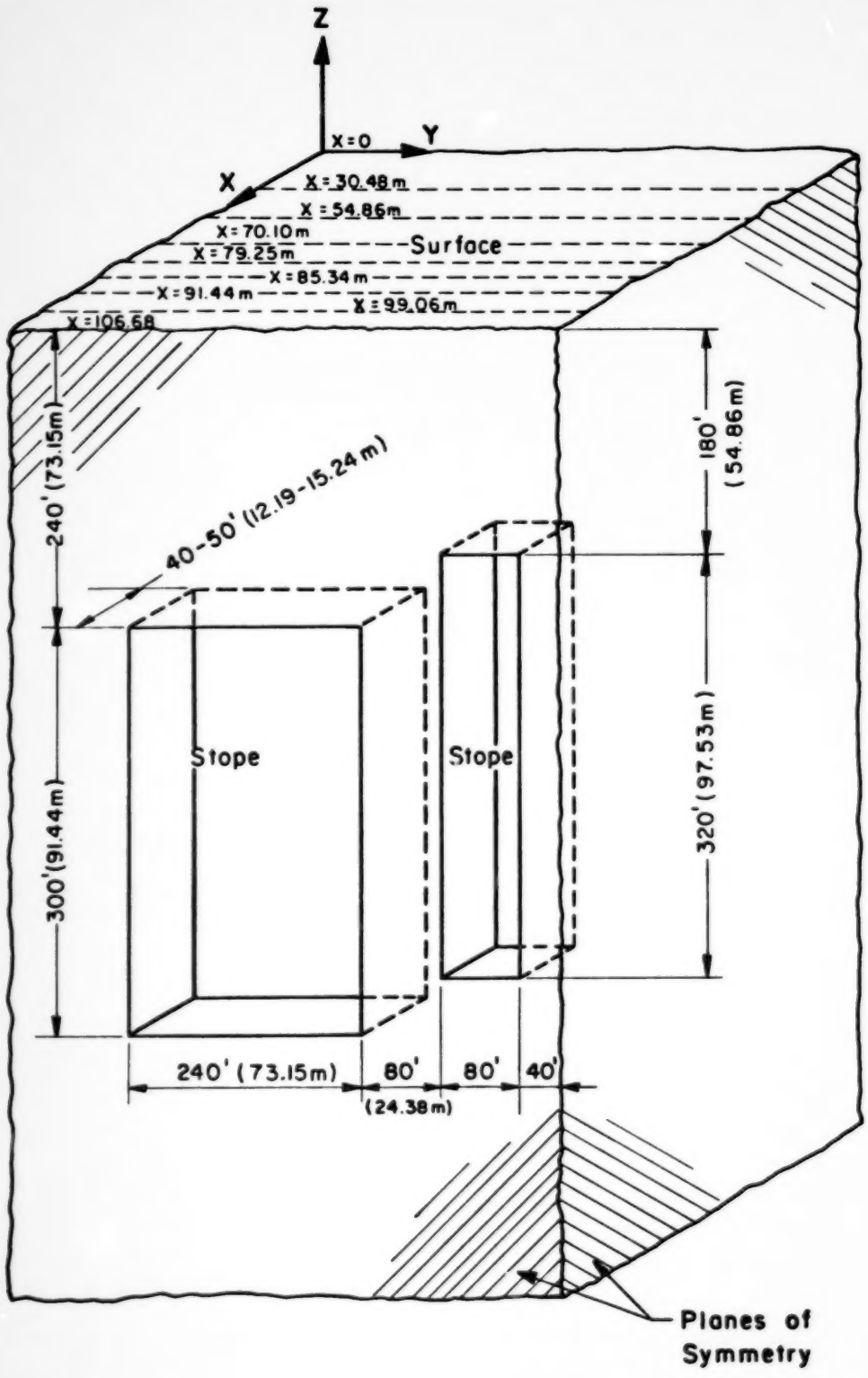


Fig. 3 Isometric View of the 3-D Niobec Mine Model

It represents only one quarter of the section of the mine being simulated. This same model was used for parallel studies including gravitational loading. Three typical model cross sections with their finite element discretizations are shown in Fig. 4(a) to 4(c). For further details on the model used, the reader is referred to Part I of Division Report M&ET/MRL 86-97(TR)[2].

The same computer program has been used for both of the analytic studies. A basic eight-node brick element with three degrees of freedom at each node is used in the program. The program performs static, and linear elastic, analysis. Material properties are assumed to be isotropic. The program is capable of handling gravitational and distributed surface loads. Initial residual stresses, if known, can also be used as input.

2.2 Material Properties of the Mine Rocks

The modulus of deformation, uniaxial compressive and tensile strengths of carbonatite were determined in laboratory tests [3]. A modulus of deformation for the limestone was determined in laboratory tensile tests; the value established, however, was considered too low for utilization in subsequent analysis. As a result, the mechanical properties for the limestone, determined in earlier Niobec studies were used.

2.3 Field Stresses

In situ stress determinations were carried out in Niobec Mine on levels 1000 and 850. The results indicate that the magnitude of the vertical stress at 850 level is greater than that measured at the level 1000. It is reasonable to believe that calculated stresses at the level 850 are probably influenced either by mining activity, or by some geological structure not yet evident.

In the Canadian Shield, it is known that the horizontal stress is greater than the vertical stress. Based on the limited stress data at the Niobec Mine, the following far field stress conditions are suggested and referred to as Loading Case B:

$$\begin{aligned} \textit{Loading Case } B: \quad \sigma_z &= \gamma Z \\ \sigma_x &= 1.5\sigma_z \\ \sigma_y &= 2.0\sigma_z \end{aligned}$$

Where; σ_z is the vertical stress at a depth Z; σ_x and σ_y are the horizontal stresses in the EW and NS directions respectively; γ is the unit weight of rock material; ν is Poisson's ratio.

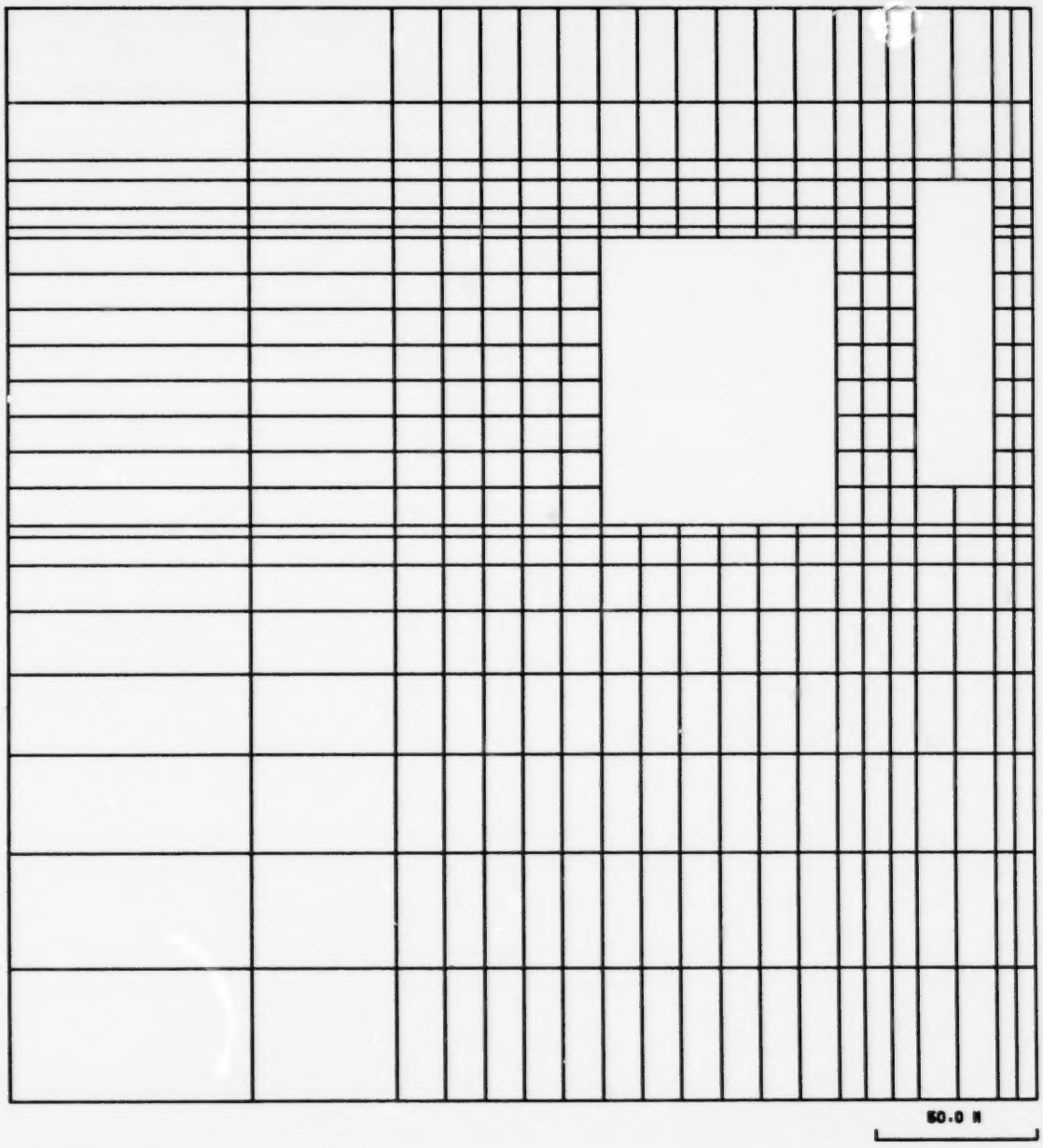


Fig. 4(a) The Finite Element Discretization for Section x=106.68 m.

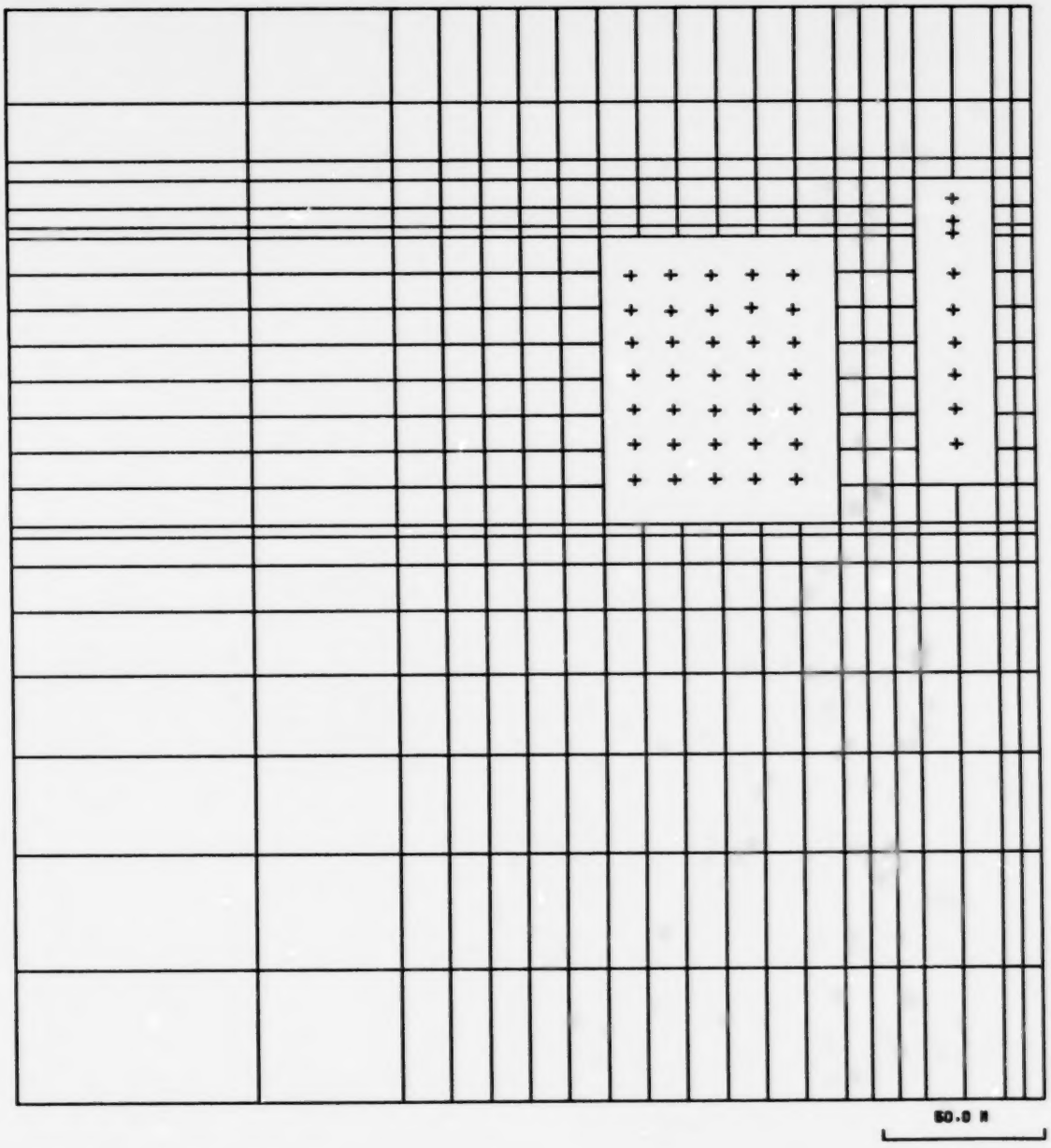


Fig. 4(b) The Finite Element Discretization for Section x=99.06 m.

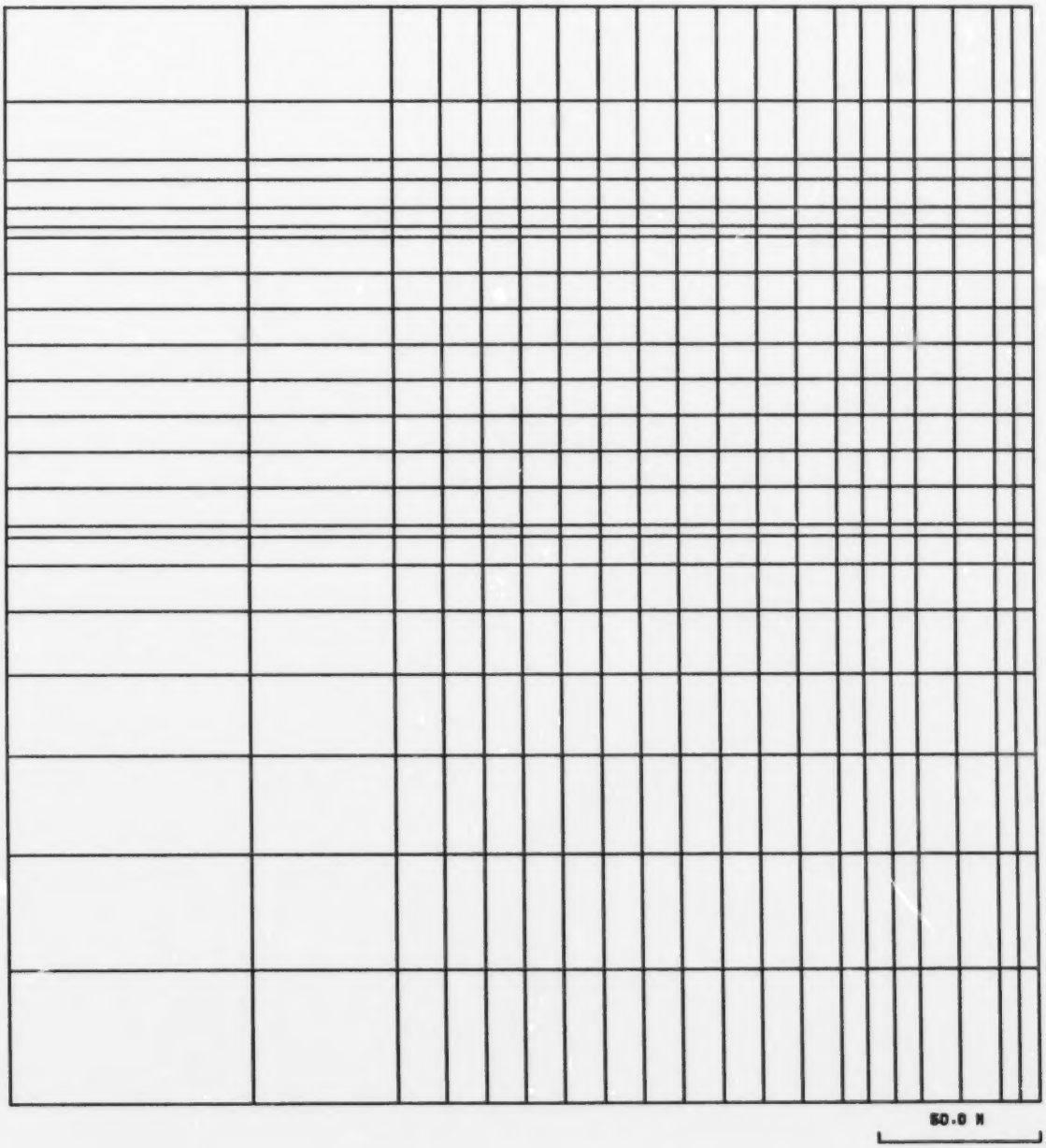


Fig. 4(c) The Finite Element Discretization for Section x=0.0 m.

3.0 RESULTS

3.1 Stress Distribution

Figures 5, 6, and 7 show the principal stress contours resu g from the simulated mining of stope C-102-23, for sections x = 102.87m, 95.25m, and 88.39m, respectively. Stresses shown in Fig. 5 (section x = 102.87) represent the average stresses in the central section of the stope. Section x = 88.39m is located at about 3m into the hangingwall or footwall. All stresses are calculated at the centroid of each element, which is located at the middle plane of each 'slice'.

As expected, the simulated mining of C-102-23 stope under existing stresses induced higher compressive stresses around the lower portion of the stope. These compressive stresses, however, were not high enough to create any ground failure problem. Tensile stress zones occur in stope walls, back, floors, and along pillars. Tensions are particularly noticeable in the stope back.

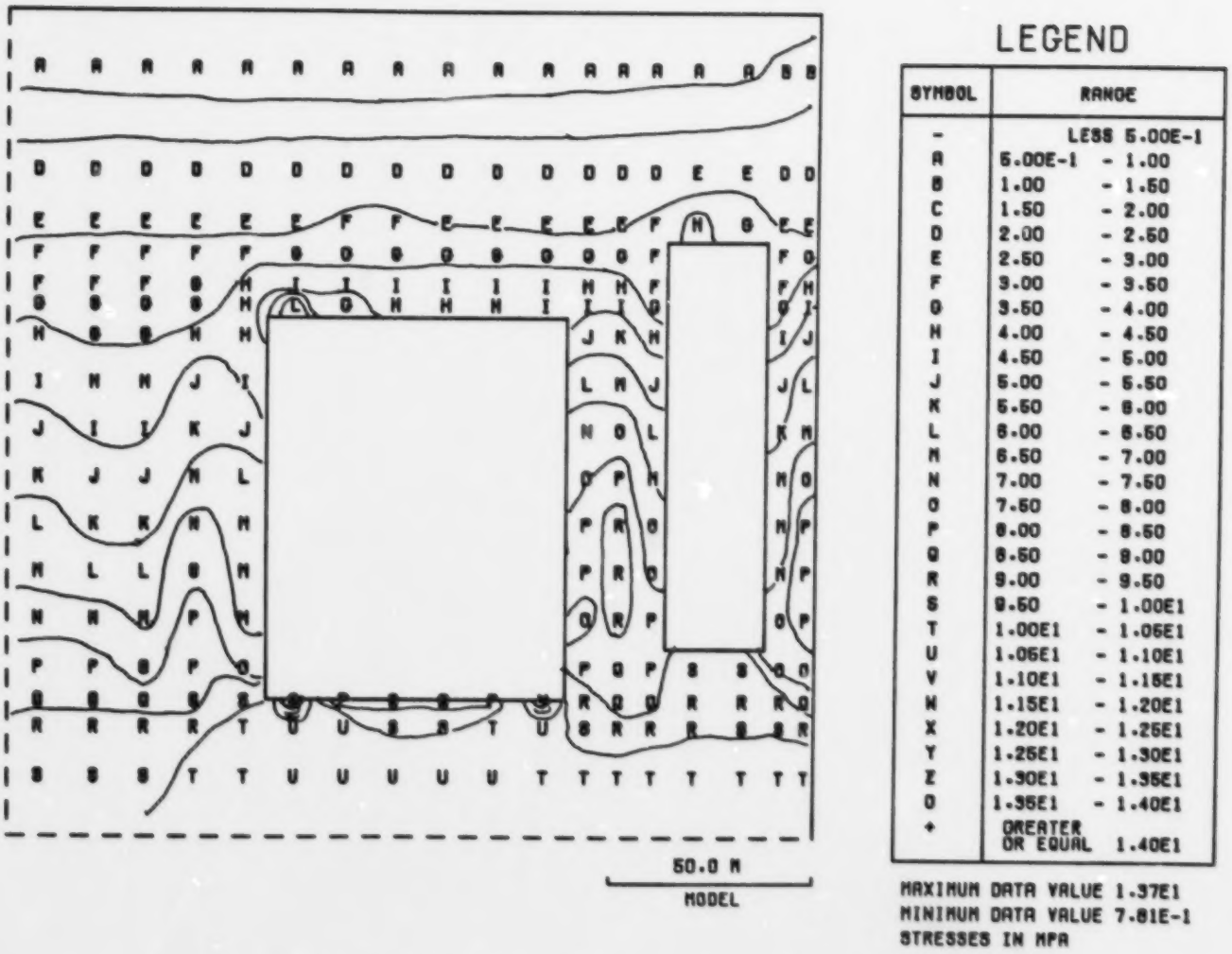
The results can be summarized as follows:

(a) Under existing stress conditions (loading B), ground stability conditions around stope C-102-23 are better than those that would occur under gravitational loading. The largest compressive stresses occur near the stope corners, with a magnitude of about 15 MPa. These are not sufficiently high to cause stability problems.

(b) Tensions developed along the walls of C-102-23 stope (T-102-21 pillar) are relatively small; all tensions are less than 0.5 MPa. However, tensions developed in footwalls and hangingwalls are slightly above those (from 0 - 0.5 MPa to 0 - 1.0 MPa) which would be realized with gravitational loading. The tensile strength of carbonatite is estimated at 5 - 10 MPa. If joints are favorably orientated wall stability should not be a problem.

(c) Small tensions (less than 0.5 MPa) occur along almost the entire height of T-102-19 pillar. Since it is only 24m wide, precautions should be taken to ensure its integrity, such as protection against blast damage.

(d) The tensile zone, developed under Loading A (gravity) in the central portion of the roof of C-102-23 stope is reduced by approximately 50 percent under Loading B. Under Loading B the tensile zone in the centre of the roof at the stope centre line is limited to a depth of 5m and extends 5m towards both the hangingwalls and footwalls. The largest tension (less than 1 MPa) is at the quarter span and diminishes gradually toward the walls. The roof of C-102-23 stope is in carbonatite. Although



LEGEND

SYMBOL	RANGE
-	LESS 5.00E-1
A	5.00E-1 - 1.00
B	1.00 - 1.50
C	1.50 - 2.00
D	2.00 - 2.50
E	2.50 - 3.00
F	3.00 - 3.50
G	3.50 - 4.00
H	4.00 - 4.50
I	4.50 - 5.00
J	5.00 - 5.50
K	5.50 - 6.00
L	6.00 - 6.50
M	6.50 - 7.00
N	7.00 - 7.50
O	7.50 - 8.00
P	8.00 - 8.50
Q	8.50 - 9.00
R	9.00 - 9.50
S	9.50 - 1.00E1
T	1.00E1 - 1.05E1
U	1.05E1 - 1.10E1
V	1.10E1 - 1.15E1
W	1.15E1 - 1.20E1
X	1.20E1 - 1.25E1
Y	1.25E1 - 1.30E1
Z	1.30E1 - 1.35E1
0	1.35E1 - 1.40E1
+	GREATER OR EQUAL 1.40E1

MAXIMUM DATA VALUE 1.37E1
MINIMUM DATA VALUE 7.81E-1
STRESSES IN MPA

Fig. 5(a) Major Principal Stress Contour, Under Loading B, for Section x=102.87 m.

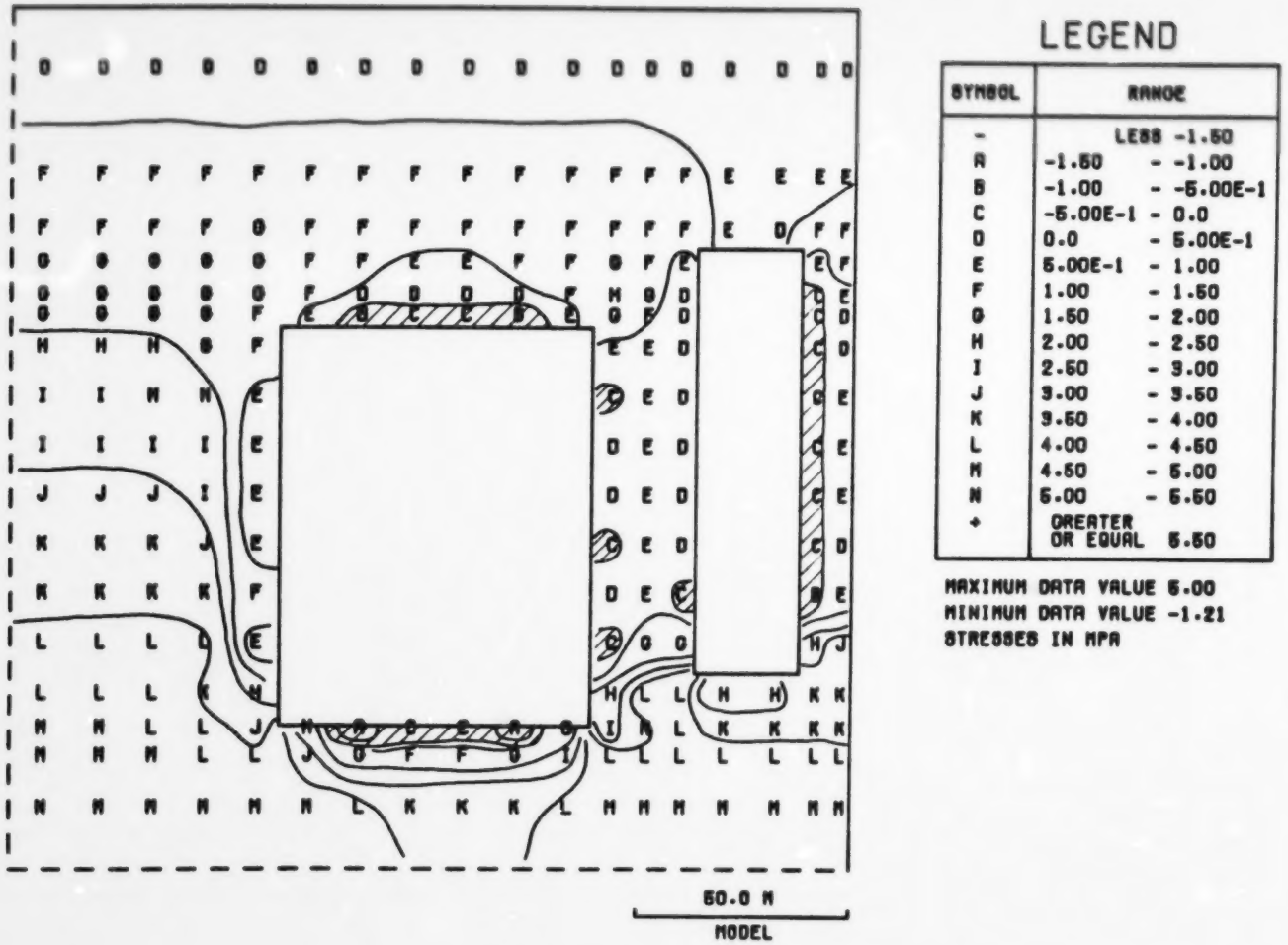
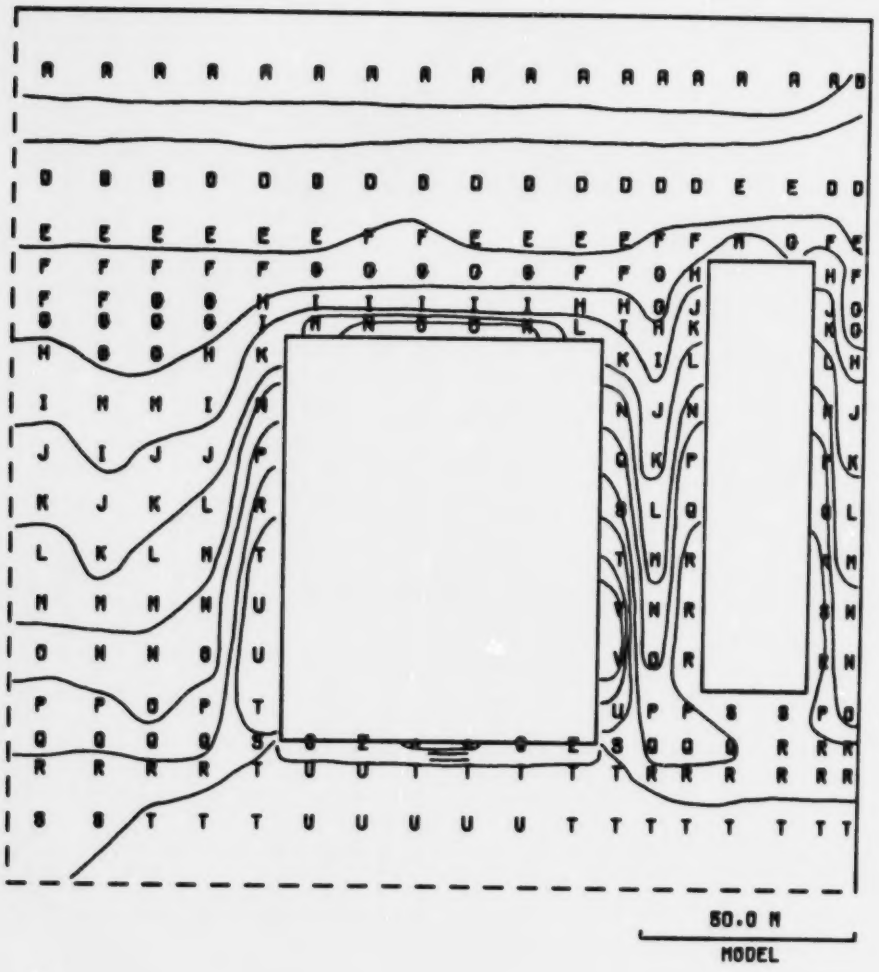


Fig. 5(b) Minor Principal Stress Contour, Under Loading B, for Section x=102.87 m.



LEGEND

SYMBOL	RANGE
-	LESS 5.00E-1
A	5.00E-1 - 1.00
B	1.00 - 1.50
C	1.50 - 2.00
D	2.00 - 2.50
E	2.50 - 3.00
F	3.00 - 3.50
G	3.50 - 4.00
H	4.00 - 4.50
I	4.50 - 5.00
J	5.00 - 5.50
K	5.50 - 6.00
L	6.00 - 6.50
M	6.50 - 7.00
N	7.00 - 7.50
O	7.50 - 8.00
P	8.00 - 8.50
Q	8.50 - 9.00
R	9.00 - 9.50
S	9.50 - 1.00E1
T	1.00E1 - 1.05E1
U	1.05E1 - 1.10E1
V	1.10E1 - 1.15E1
W	1.15E1 - 1.20E1
X	1.20E1 - 1.25E1
Y	1.25E1 - 1.30E1
Z	1.30E1 - 1.35E1
0	1.35E1 - 1.40E1
+	GREATER OR EQUAL 1.40E1

MAXIMUM DATA VALUE 1.43E1
MINIMUM DATA VALUE 7.80E-1
STRESSES IN MPA

Fig. 6(a) Major Principal Stress Contour, Under Loading B, for Section x=95.25 m.

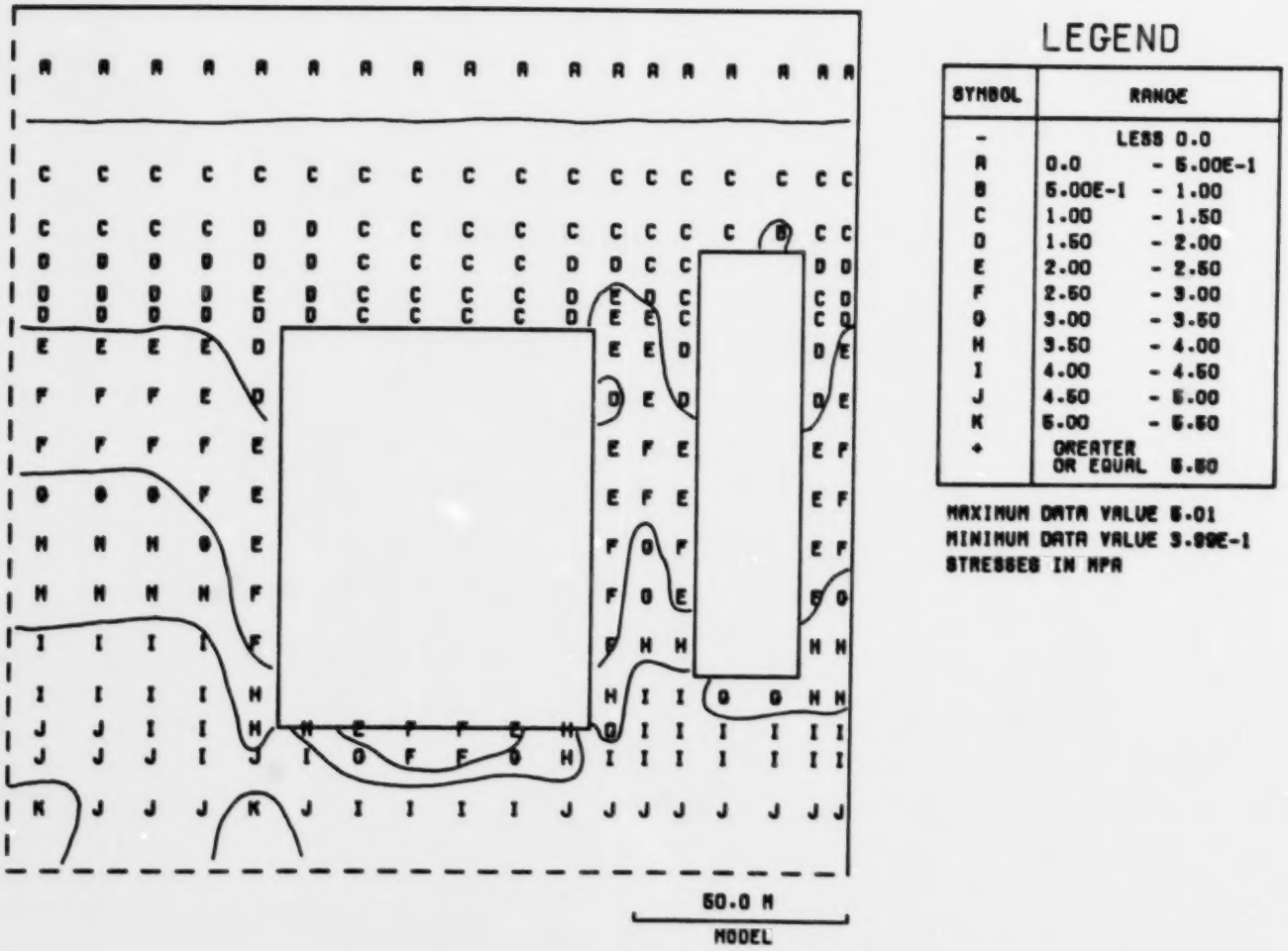


Fig. 6(b) Minor Principal Stress Contour, Under Loading B, for Section x=95.25 m.

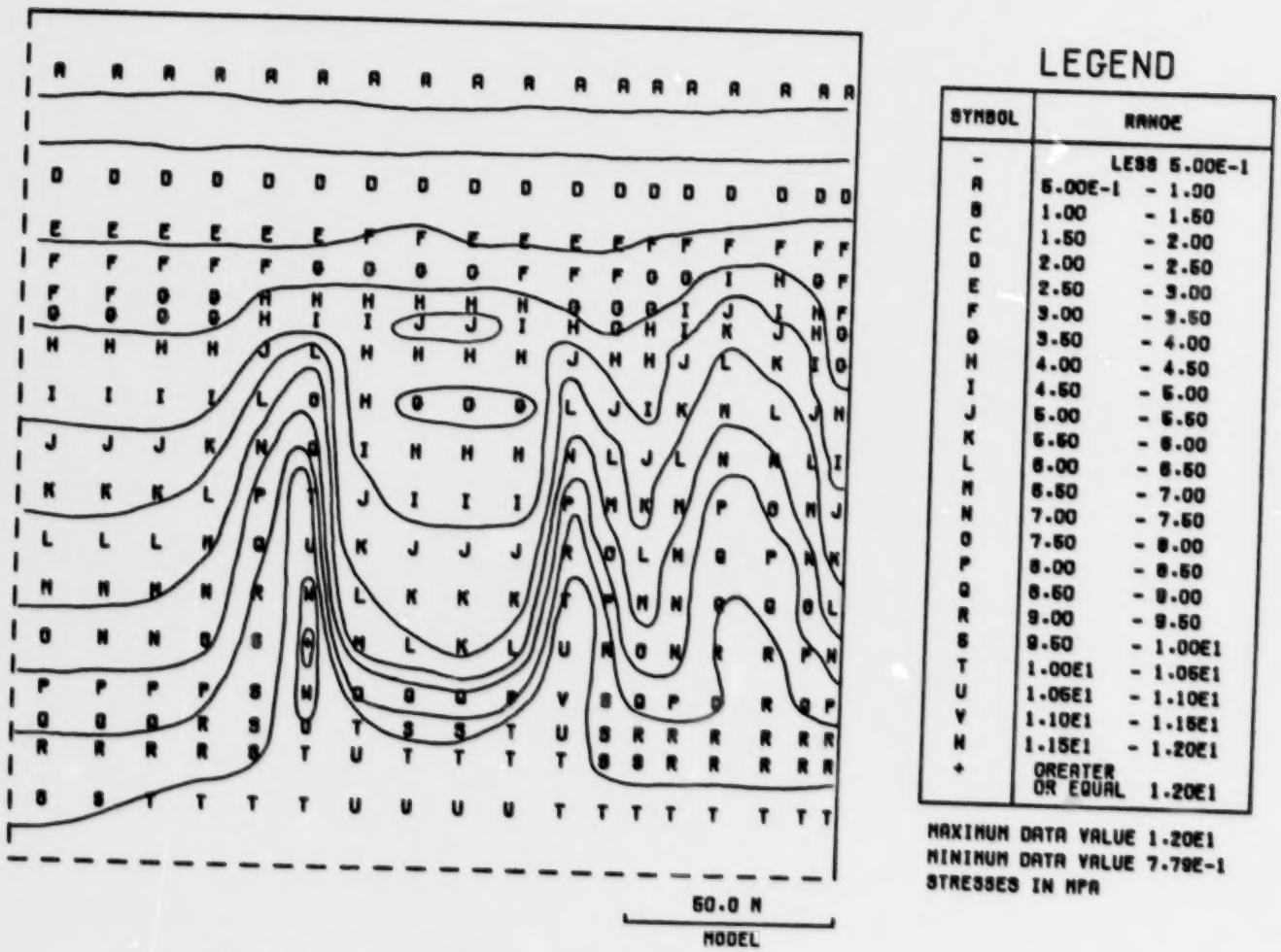


Fig. 7(a) Major Principal Stress Contour, Under Loading B, for Section x=88.39 m.

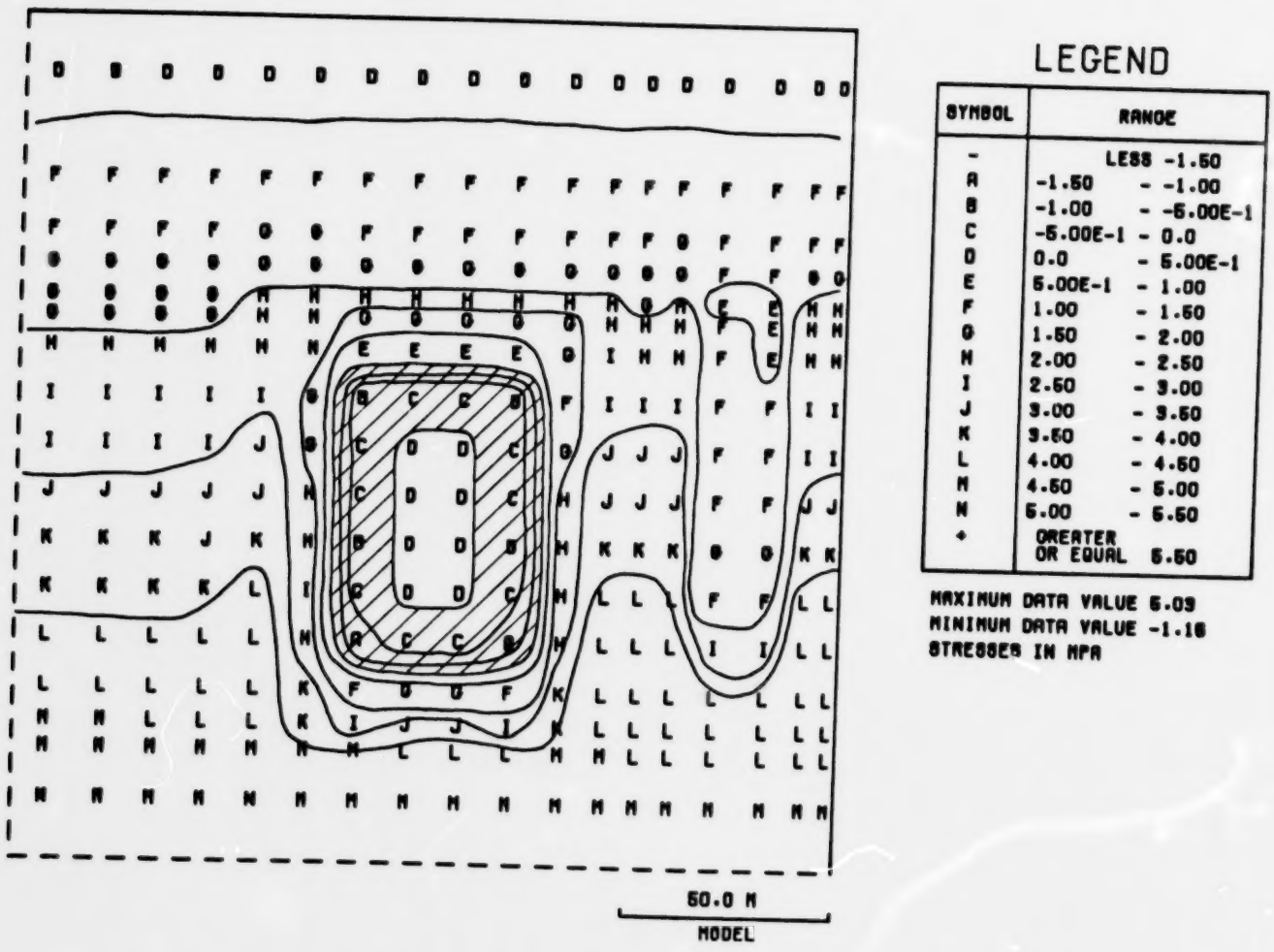


Fig. 7(b) Minor Principal Stress Contour, Under Loading B, for Section x=88.39 m.

roof load conditions under Loading B are more favourable than roof load conditions under Loading A, ground conditions around C-102-23 stope should be regularly observed as mining of C-102-23 stope progresses. If adverse ground conditions develop, additional pillars should be considered.

(e) It is interesting to note that large tensions (approximately 1 - 1.21 MPa) also occur in the floor of C-102-23 stope with Loading B. Floor heaving should be expected.

3.2 Safety Factor

Local factors of safety in terms of the Drucker/Prager yield function have also been calculated for the three sections under consideration, i.e., for the planes x = 102.87m, 95.25m and 88.39m. These are shown in Figs. 8, 9, and 10. The material constants used for this analysis were $C = 2$ MPa and $\phi = 40°$ where C is the cohesive strength and ϕ the angle of internal friction. No yield zones are indicated (factor of safety $\leq$ 1.0). The values used in the study for cohesive strength C and angle of internal friction ϕ, 2 MPa and 40° respectively, can be considered conservative. Therefore, shear failure in the roof or pillars is not likely to occur under either Loading A or Loading B conditions.

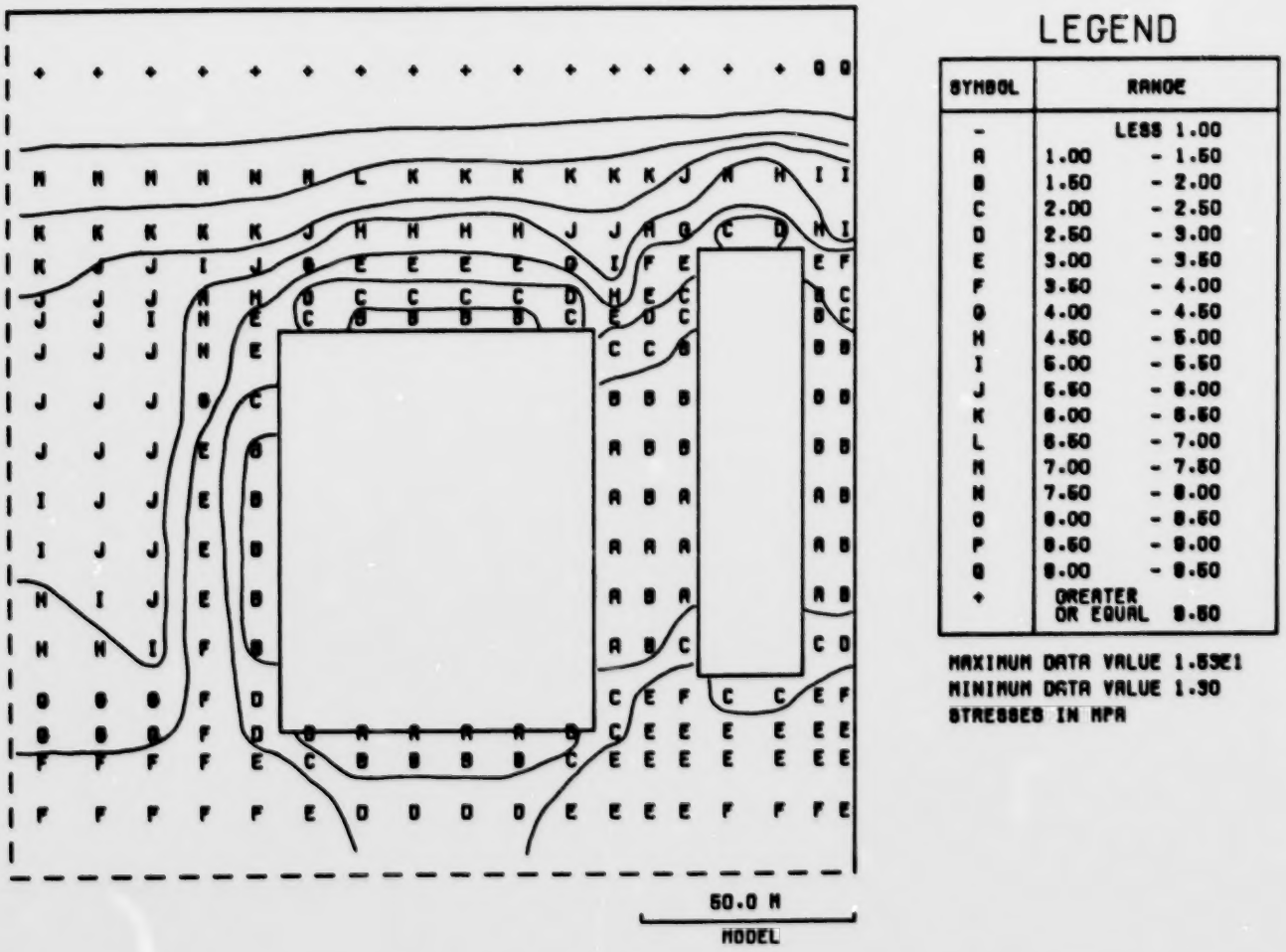
3.3 Average Pillar Stresses

The average pillar stresses for T-102-21 and T-102-19 were evaluated based on the vertical stresses acting at the middle height of each pillar. The average vertical pillar stresses for T-102-21 and T-102-19 are 2.92 MPa and 2.54 MPa , respectively. The average stresses in the transverse direction of the pillars were also evaluated for T-102-21 and T-102-19; they are 7.76 MPa and 6.46 MPa, respectively.

If the material obeys the Coulomb criterion of brittle failure, then, the uniaxial compressive strength, σ_u, can be related to the rock formations cohesive strength and angle of internal friction, i.e., $\sigma_u = 2C(1 + \sin\phi)/(1 - \sin\phi)$. If C = 2 MPa, $\phi = 40°$, the uniaxial strength σ_u calculated is 18.38 MPa. The compressive strengths for the intact and altered carbonatite are 130 Mpa and 90 MPa, respectively [3]. On this basis, local factors of safety calculated for the pillars based on the above assumptions, are more than adequate. Therefore, no imminent shear failure is anticipated. If failure occurs, it would be localized tension failure rather than shear failure.

4.0 CONCLUSIONS AND RECOMMENDATIONS

(a) Ground stability conditions around C-102-23 stope are more favourable under existing ground stress conditions than under gravitational loading. The tensile zone in the



LEGEND

SYMBOL	RANGE
-	LESS 1.00
A	1.00 - 1.50
B	1.50 - 2.00
C	2.00 - 2.50
D	2.50 - 3.00
E	3.00 - 3.50
F	3.50 - 4.00
G	4.00 - 4.50
H	4.50 - 5.00
I	5.00 - 5.50
J	5.50 - 6.00
K	6.00 - 6.50
L	6.50 - 7.00
M	7.00 - 7.50
N	7.50 - 8.00
O	8.00 - 8.50
P	8.50 - 9.00
Q	9.00 - 9.50
+	GREATER OR EQUAL 9.50

MAXIMUM DATA VALUE 1.65E1
MINIMUM DATA VALUE 1.30
STRESSES IN MPA

Fig. 8 Drucker/Prager Safety Factor Contour, Under Loading B, (C=2 MPa; $\phi = 40°$), for Section x=102.87 m.

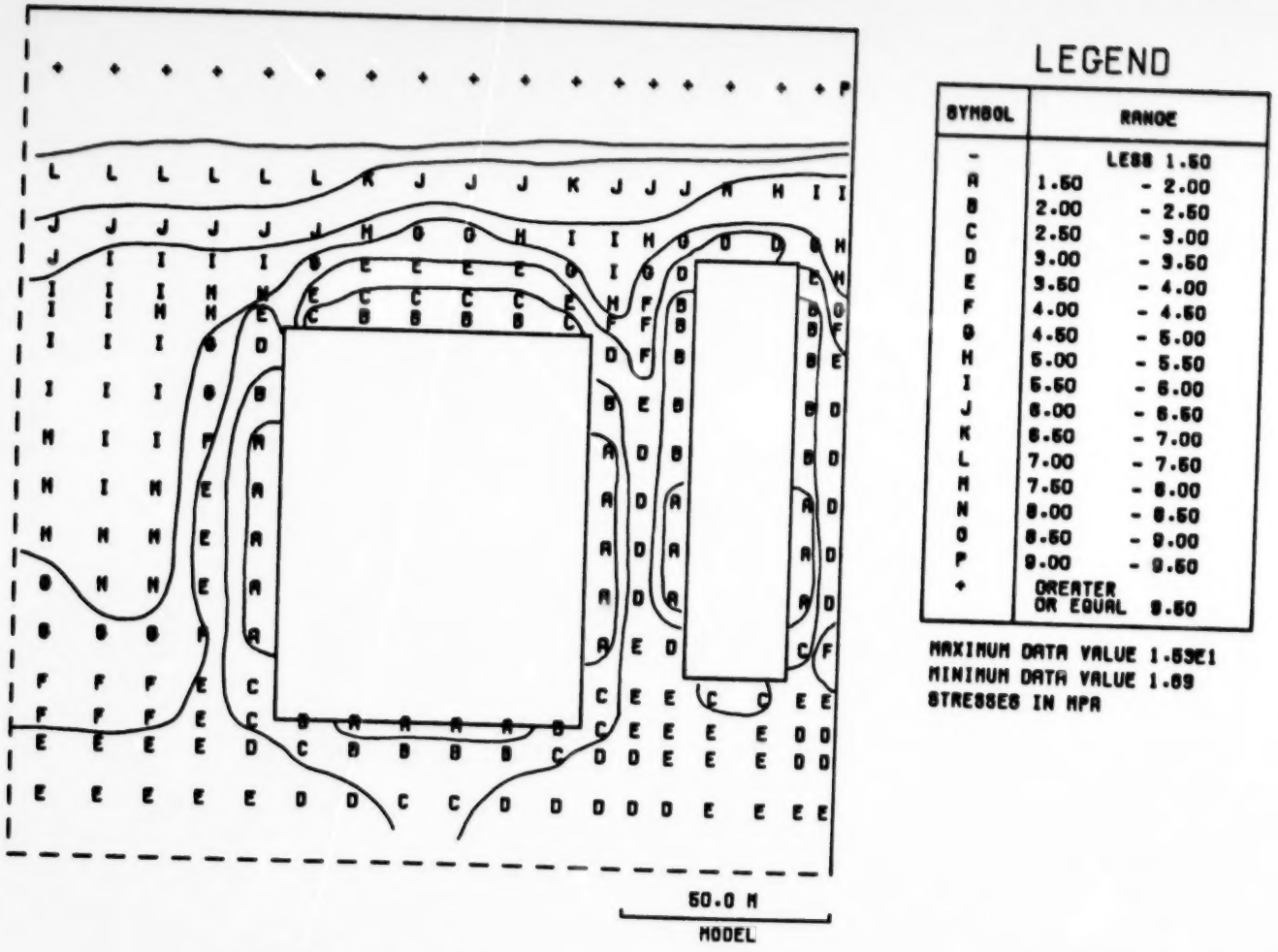
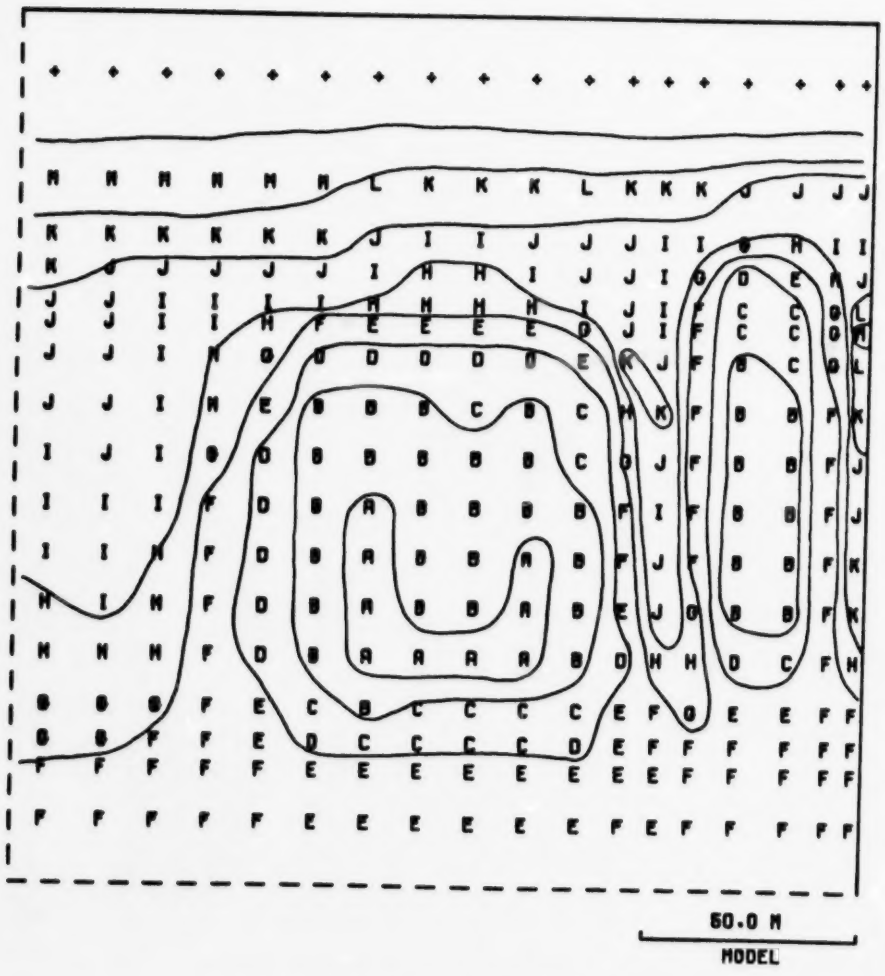


Fig. 9 Drucker/Prager Safety Factor Contour, Under Loading B, (C=2 MPa; $\phi = 40°$), for Section x=95.25 m.



LEGEND

SYMBOL	RANGE
-	LESS 1.00
A	1.00 - 1.50
B	1.50 - 2.00
C	2.00 - 2.50
D	2.50 - 3.00
E	3.00 - 3.50
F	3.50 - 4.00
G	4.00 - 4.50
H	4.50 - 5.00
I	5.00 - 5.50
J	5.50 - 6.00
K	6.00 - 6.50
L	6.50 - 7.00
M	7.00 - 7.50
N	7.50 - 8.00
O	8.00 - 8.50
P	8.50 - 9.00
Q	9.00 - 9.50
*	GREATER OR EQUAL 9.50

MAXIMUM DATA VALUE 1.54E1
MINIMUM DATA VALUE 1.16
STRESSES IN MPA

Fig. 10 Drucker/Prager Safety Factor Contour, Under Loading B, (C=2 MPa; $\phi = 40°$), for Section x=88.39 m.

back of C-102-23 stope decreased by approximately 50 percent. Conventional rock bolting to strengthening the roof is not sufficient because of the depth of the potential tensile failure zone. Cable bolting with suitable lengths of cable for anchorage beyond the tensile zone is recommended.

(b) As expected, the mining of C-102-23 stope under existing stresses will induce higher compressive stresses in the lower portion of the stope. Compressive stress levels of about 15 MPa will be developed in the stope floor. These are not sufficiently high to cause a ground stability problem.

(c) Pillars presently consist of carbonatite. The average pillar stresses in both vertical and transverse directions are low (2.5 - 7.8 MPa), compared with the uniaxial compressive strength of carbonatite (130 - 90 MPa). Therefore, shear failure of the pillars is not a concern.

(d) Tensile stresses occur in stope walls, back and floor, and pillars. However, the stresses are small (0 - 1 MPa) when compared with the tensile strength of carbonatite (5 - 10 MPa). Localized tensile failure may develop if joints are oriented favourably in relation to tensile stress directions. As mining progresses in stope C-102-23. it should be subject to continuous observations. If adverse ground conditions develop additional pillars should be considered.

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